

447

Biological Productivity

by

E. H. Grainger

Arctic Biological Station,
Fisheries and Marine Service,
Department of the Environment,
Ste. Anne de Bellevue, Que.

MANITOWAG A. V. E. H. GRAINGER
EXHIBIT NO. 447 February 10/76
Inch out.
C.O.P.E.

21 January 76

The arctic marine environment is characterized by low water temperature, a sea ice cover which prevails over a large part of each year, little sunlight penetration beneath the sea surface during most of each year, and a very highly developed seasonality. These features set the arctic marine environment aside from warmer water regions all over the world.

A figure (Fig. 1) may make this point better than words. The horizontal scale shows the span of a year (January to December), the vertical scales various of the qualities measured. On the vertical scales quantities may be ignored; what is meaningful, is that values increase from bottom to top. Ice and snow cover (lower left) reach maximum thickness around May, then fall rapidly, the ice disappearing by July. With the thinning of the ice, sunlight increases beneath the sea surface (shown as light at 5 metres). Its peak is reached in July, as the ice disappears (without an ice cover it would peak in late June when daylight times are greatest for the year), and it then falls off gradually. With increase in light availability, the small, single-celled marine plants, the phytoplankton, (shown here as chlorophyll a) grow and reproduce and reach their seasonal maximum in quantity soon after maximum light availability. These plants undergo photosynthesis, in which they use the energy of available sunlight to convert inorganic chemicals into organic materials (themselves) and in which they produce oxygen. One of the inorganic substances they use is a compound containing nitrogen (nitrate in the figure), which increases in quantity during winter in the sea, when plant activity is almost totally stopped under the sea ice cover. With the development of plant activity in



Digitized by the Internet Archive
in 2025 with funding from
University of Toronto

<https://archive.org/details/31761120644034>

May-June, nitrate begins to decline, and continues to do so until the plants reach their peak in August. The plants (the chlorophyll a in the figure) are the food of the small, plant-eating (herbivorous) zooplankton. These increase their numbers with the production of young as plant food becomes available in early summer, and fall off through the late summer and fall. The decline in chlorophyll in this figure was probably mainly a result of predation by zooplankton. The fall in numbers of zooplankton was in turn probably initiated by larger, animal-eating (carnivorous) zooplankton and fishes (not shown in the figure). Through October and November, winter conditions developed, and in December the sea ice cover formed and began to grow.

This figure is not based upon data obtained in the Beaufort Sea, but the tremendous seasonality and the major lines of dependence in the arctic region shown here certainly relate very obviously to the Beaufort Sea. Our Beaufort Sea study did not allow the depiction of the year-round data which was given in the figure, and which came from an eastern Canadian arctic locality.

No part of the actual Beaufort Sea Project open-water study, and this applies to the work undertaken in 1974 and 1975, was carried out under favourable circumstances. The ship-supported surveys of the two summers failed so badly to achieve the schedules planned for them, that most of the data strength of the study originated therefore either in the year preceding initiation of the Beaufort Sea Project or through the use of helicopters on the early summer sea ice cover. This was largely the consequence of sea ice persisting over areas where studies from shipboard had been planned. It had important consequences to this

study, and it showed in a very clear way the fallacy of underestimating the arctic by presupposing a capacity to perform in it under all conditions.

The present investigation did not achieve its expectations in terms of range of coverage, either in space or in time. A number of rather elementary questions concerning base-line features of this ecosystem therefore remain unanswered. Such gaps show the report to be even more of a preliminary one than it was hoped it would be when the plan was conceived.

The essentially base-line studies which I am reporting on here were for the most part concerned with the sequence of relationships shown in the figure (Fig. 1). The "lower" end of the ecosystem on which the fishes, sea birds, seals and whales are to such a great degree dependent.

It must be pointed out here, even though the physical oceanographers may already have described it, that much of the coastal portion of the eastern Beaufort Sea is estuarine in nature. This means that the relatively warm (in summer) fresh water of the Mackenzie River flows beyond the river mouth largely over the colder, saltier (and therefore heavier) water of the Beaufort Sea. This area of visible river influence, made especially obvious in the Beaufort Sea by the heavy silt load carried seaward by the Mackenzie, is highly variable in its size, shape and location. Driven off shore by southerly winds it is at its largest and extends farthest off shore.

Following onshore winds, the fresh water area is reduced in extent and forced shoreward. Largely because of its silt load, light penetration is greatly inhibited in the low-salinity river water. Outside this,

the clear oceanic waters allow fairly deep penetration of light. In the river water region, nutrients (nitrate, for instance) are abundant, contributed by the river, but they are largely useless because the plants, with insufficient light, are largely unable to use them. Outside the area of river influence, generally sufficient light (in summer) is not accompanied by adequate nutrients. Once the relatively small winter-produced supply is used up, the surface waters are nutrient-poor, so after the first bloom of spring, production largely stops because of nutrient deficiency.

The second figure (Fig. 2) shows light penetration in the south Beaufort Sea. The area of primary river influence is shown by the very low values (1 and less), the clear offshore waters by higher values.

In Fig. 3, nitrate-nitrogen near shore and away from shore is shown, with the highest values coinciding in large part with low light areas, the low offshore values with deep penetration of light.

We cannot at present show the geographical distribution of production of plants in the south Beaufort Sea. Indirect evidence points to lowest values in the nearly fresh, silt-laden waters just off the river mouth. Far offshore, well beyond the river influence, production also seems to be low, following the initial surge in early summer which probably uses up most of the available food for the plants. Higher values seem to occur near the outer edge of the area of river influence (where nutrients and light are suitably combined) and perhaps in the shallow coastal bays outside the area of turbid river water.

Quantities of plant material in summer are fairly consistently low on the basis of chlorophyll a measurements, by arctic and by world

standards--averaging, for instance, about one fifth the quantities measured at the same times of the year in a fully marine Canadian arctic locality in southeast Baffin Island.

The small zooplankton animals were distributed quantitatively as shown in Figure 4, in which the highest levels (greatest numbers of animals per unit of water sampled) were found in coastal bays, the lowest levels nearest the river mouths and far offshore, and the middle levels generally near the outer limit of the area of principal river influence. Some of the levels measured were high by arctic standards, but the great majority were low by virtually all regional standards, and bore a similar relationship to the Baffin Island quantities as was shown by the plants.

Evidently the south Beaufort Sea is a region of low marine production.

Crude oils evidently had no effect upon rates of nitrogen fixation of bacteria of the Beaufort Sea substrate, which is to say that the capacity of the bacteria to transform the element nitrogen, in which form it is unusable by plants, to a form in which it becomes available to parts of the biological cycle, does not seem to be altered at least by short-term exposure to oil. Natural fixation rates appeared to be extremely low in Beaufort Sea samples, but were experimentally accelerated by addition of carbon compounds, showing a potential which natural conditions evidently did not allow to be realized.

In a similar way, denitrification, which is the return to elemental nitrogen from the useable nitrogen compounds, was unaffected by oils as was carbon dioxide production.

Examination showed an abundant population of heterotrophic bacteria

(that is, bacteria utilizing complex organic materials rather than the simple inorganics of the light-stimulated autotrophic forms) with oil degrading potential in the Beaufort Sea. Largest cell counts were made in surface river water north of the Tuk Peninsula. Laboratory culturing showed that all the areas of the Beaufort Sea sampled supported bacterial populations with a potential for biodegradation at 5°C. In fact, a biodegradation potential has been found at as low a temperature as -1°C. Nitrogen may be the principal limiting nutrient affecting metabolic activity of these organisms.

Effects of 4 types of crude oil (Atkinson Pt., Norman Wells, Pembina and Venezuela) on phytoplankton productivity rates varied from inhibition to stimulation, depending not only on the species of plants, but as well on location, duration of the experiment, concentration of oil and the use of dispersants. The use of Corexit with crude oils generally inhibited productivity.

Two seaweed species were examined for the effect of oil, and productivity of both species was found to be significantly inhibited by all types and concentrations of oils tested.

The threads that tie these studies together are the lines that run through the ecosystem under study, the fundamental dependence of each level upon those below it in the system structure. A major line of energy transfer is the food chain, and this is a pathway for pollution. The primary plants utilize inorganic nutrients (N, P, Si) and sunlight in the synthesis of organic material. These in turn are the prey of plant-eating zooplankton, mainly small copepods at this stage. Next come predatory (carnivorous) zooplankton, a few larger copepods, but

107
mainly medusae (jelly-fish), ctenophores (comb-jellies), chaetognaths (arrow-worms) and pelagic fishes (principally the arctic cod). Other fishes prey on larger zooplankton and on smaller fishes, and the mammals on the larger invertebrate animals and on fishes. Within this scheme of things are the bottom-dwelling invertebrates, which subsist mainly on the rain of detritus and other elements from the plankton above, as well as on each other, and which are the prey of larger bottom animals, including fishes and bottom-feeding mammals.

It is a characteristic of cold northern waters that the number of species of plants and animals is small, relative to what is found in warmer seas, but that proliferation of individuals of certain of the few species is great. Hence we have a small number of species, a few of which are dominant and account for the large majority of the individuals. This is a simple system, compared to one in which the total diversity is greater and none of the species is dominant. Relationships based upon who eats whom are simply illustrated in the Beaufort Sea. They show that the chains are usually short and have few links. Typical sequences are diatom to copepod to fish, diatom to copepod to amphipod to seal; flagellate to euphausiid to whale. Options in these energy pathways are few, and vulnerability is therefore high.

One extremely important part of the system, significant in food chain building, is the under-ice biota. This is a feature of arctic seas, a response to the ice cover which overlies the sea for a long part of each year. A special flora, comprised of diatoms, develops under the ice as winter progresses and the ice thickens. Evidently using nutrients available in the ice, the cells grow and divide, forming dense

concentrations on and just within the lower surface of the ice. These plants may account for a significant proportion of total primary carbon production in a region over a year, and the flora provides a large, upside-down feeding surface for small planktonic animals and forms the base of a food chain which includes the arctic cod, probably the most important pelagic fish in the Beaufort Sea, as well as seals and whales.

Fixed in position, rather like an upside-down sea bottom community, the under-ice flora would appear to be highly vulnerable to oil effects, on the basis of a total lack of avoidance capacity and of the effects of oil on most plants cultured in the laboratory. If significant disruption of the under-ice flora occurs, then the effects may be expected fairly quickly to extend through the ice-based food chain.

Partly fixed in position are many members of the sea bottom fauna. Some move only very slowly, hence have only low capabilities for avoidance. Some move fairly quickly, but even they are restricted to a 2-dimensional surface, and cannot leave it. Especially in shallow bays these populations are in a highly vulnerable position as a consequence of oil impact. Their role as food is particularly important to the bottom fishes and to diving birds and sea mammals.

It's been suggested before that biological systems are complex and highly variable. They are. Whole systems undergo seasonal and annual variations. More troublesome are the highly individual variations found in different species and within single species at different periods of their cycles and under an almost overwhelmingly large number of other variables related to their physiological condition and their external circumstances.

As a start it is absolutely essential that we derive a considerable degree of understanding of undisturbed or "normal" systems before we can appreciate many of the impact effects in any full sense. There is a requirement here for a great deal of work which must extend over a fairly long period of time.

In the Beaufort Sea (and in most of the remaining marine areas of the Canadian arctic) there are requirements to study ecosystems over periods of several years, and in all seasons of those years, to demonstrate normal annual and seasonal variations in all levels of the systems, and to define the major governing factors which make the systems go.

Superimposed over this are studies designed to respond to specific anticipated impacts, many of them, in their relevance to a particular system, dependent upon knowledge of the basic system itself.

In the Beaufort Sea, for instance, there is no evidence at present that crude oil contamination of short duration will influence nitrogen fixation or denitrification by bacteria in the sea bottom. There is however the possibility of long-term effects, and there is a need for examination of this possibility. This is a recommended future task, important in any case, but with a significance possibly increased by our knowledge of the long-term natural rates of these activities in the sea bottom, their dependence upon variable nutrient supplies, and their overall role in the biology of the system, all matters about which we know very little at the moment. Here a recommended impact study could be greatly enhanced in its significance by additional work of a basic nature. The two approaches are not at all clearly distinguishable; in

REFERENCES

- Bunch, J. N. 1976. Biodegradation of crude petroleum by the indigenous microbial flora of the Beaufort Sea. Beaufort Sea Project Tech. Rep. 10.
- Grainger, E. H. 1975. Biological productivity of the southern Beaufort Sea: The physical-chemical environment and the plankton. Beaufort Sea Project Tech. Rep. 12 (Part I): 82 pp.
- Hsiao, S. I. C. 1976. Biological productivity of the southern Beaufort Sea: phytoplankton and seaweed studies. Beaufort Sea Project Tech. Rep. 12 (Part II): 137 pp.
- Knowles, R. 1975. Nitrogen fixation in arctic marine sediments. Beaufort Sea Project Tech. Rep. 9: 44 pp.
- Wacasey, J. W. 1976. Biological productivity of the southern Beaufort Sea: zoobenthic studies. Beaufort Sea Project Tech. Rep. 12 (Part III).

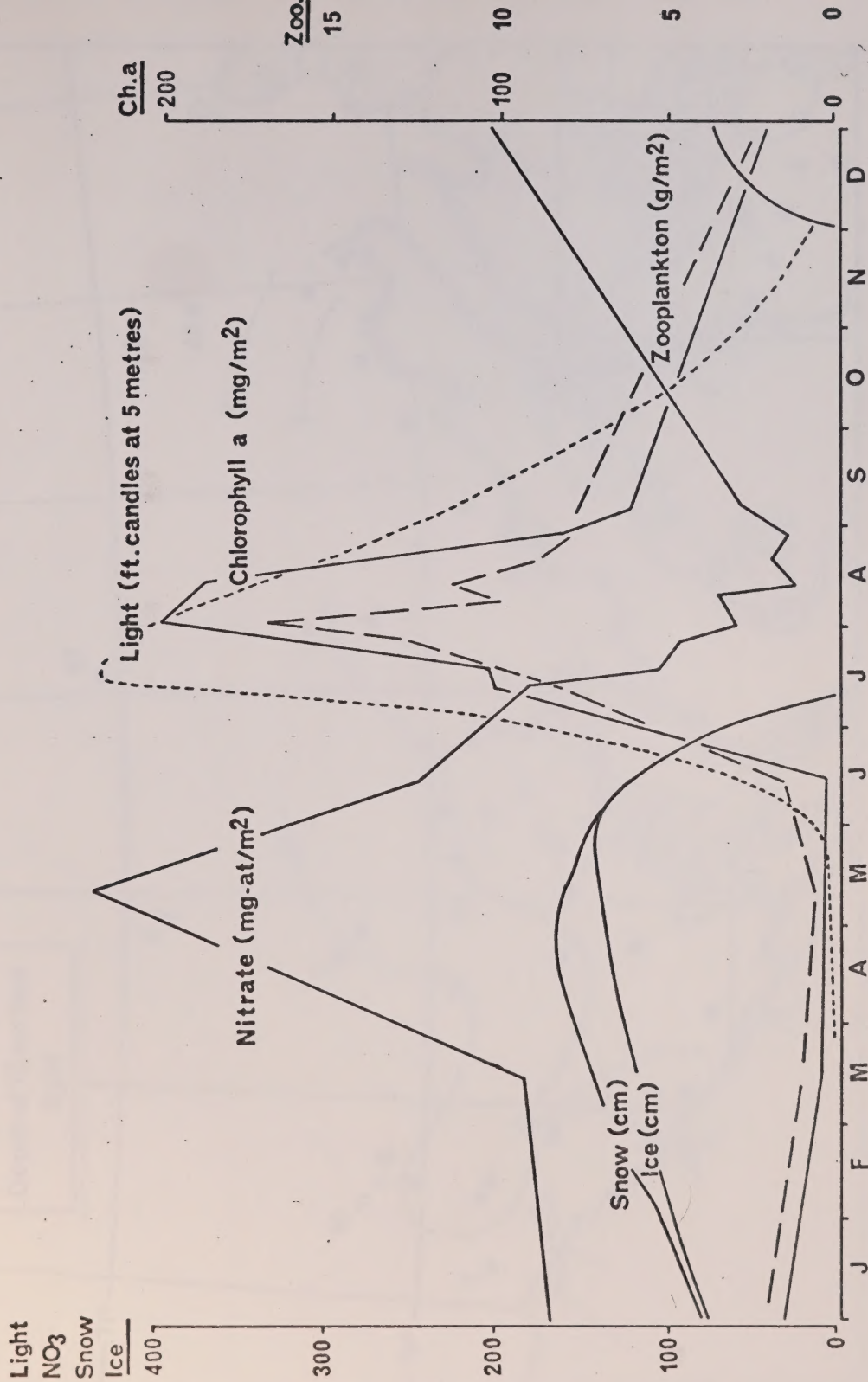


Fig. 1. Seasonality in an arctic marine ecosystem.

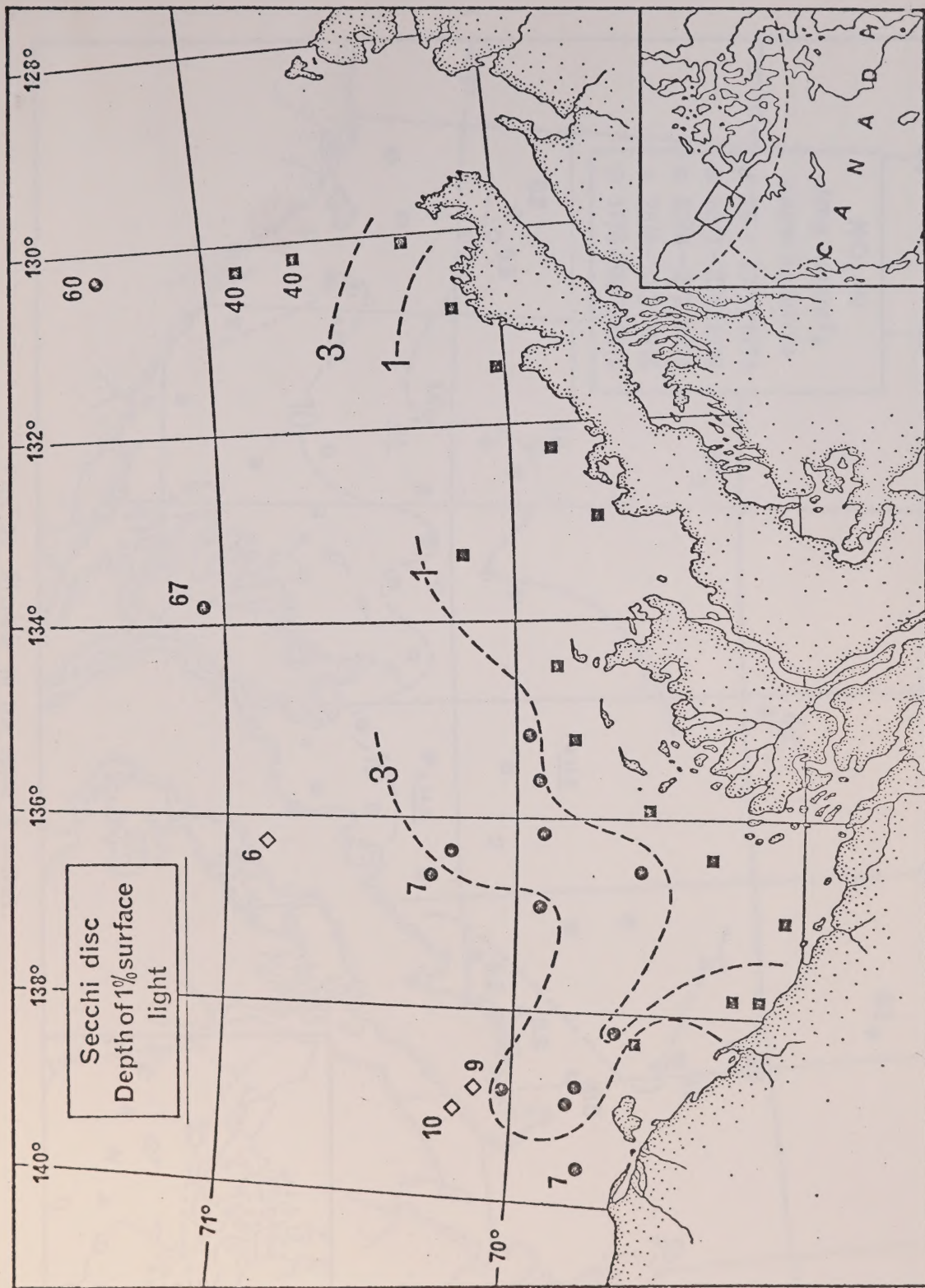


Fig. 2. Depths of light penetration beneath the surface of the sea.

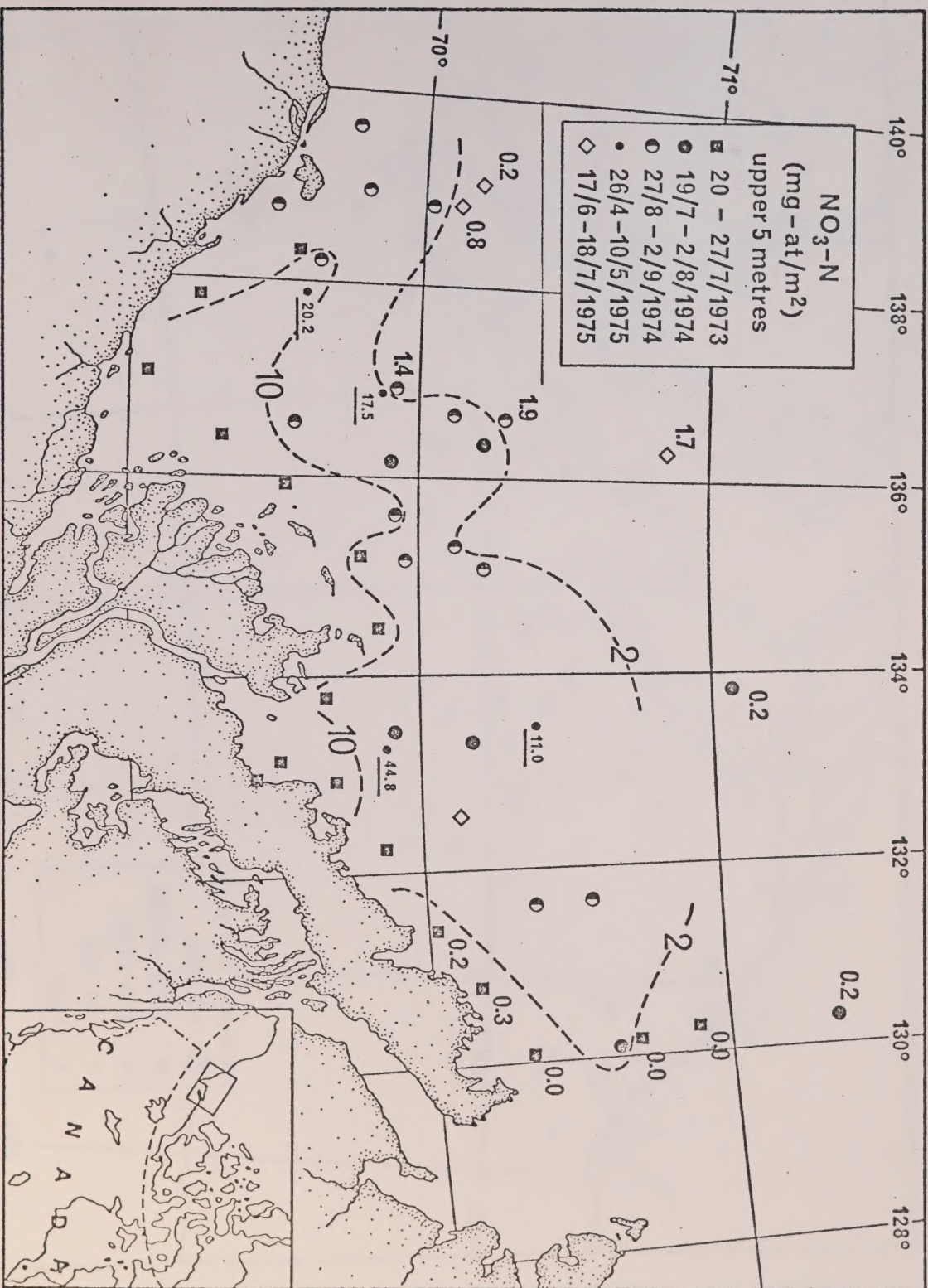


Fig. 3. Nitrate in the upper 5 metres.

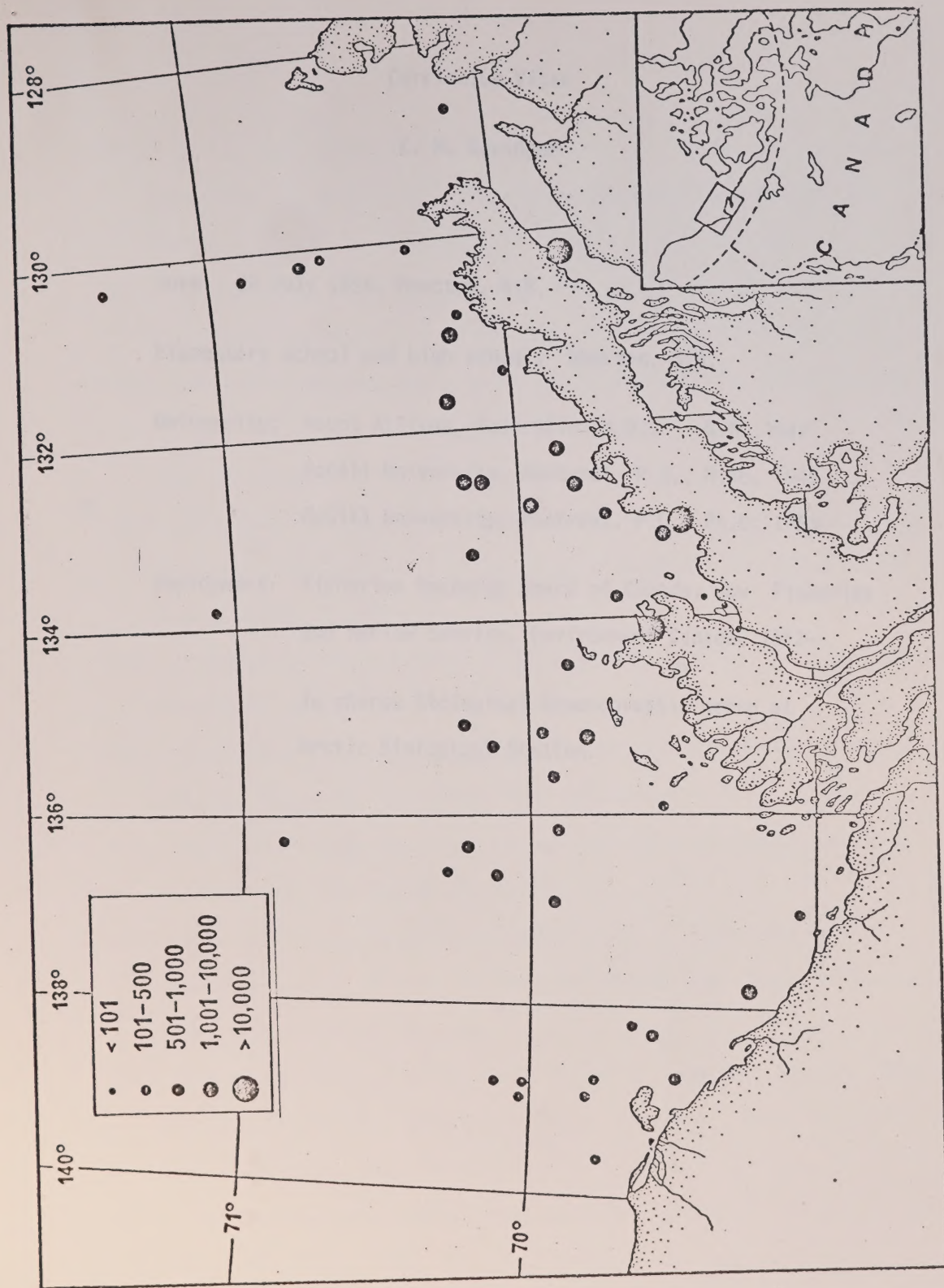


Fig. 4. Numbers of zooplankton individuals per cubic metre.

Curriculum Vitae

E. H. Grainger

Born: 24 July 1926, Moncton, N.B.

Elementary school and high school: Moncton, N.B.

University: Mount Allison, Sackville, N.B., B.A. 1947

McGill University, Montreal, P.Q., M.Sc. 1949

McGill University, Montreal, P.Q., Ph.D. 1953

Employment: Fisheries Research Board of Canada, now Fisheries
and Marine Service, Environment Canada, 1953--

In charge Biological Oceanographic group at
Arctic Biological Station.

Representative publications - E. H. Grainger

1953. On the age, growth, migration, reproductive potential and feeding habits of the arctic char (Salvelinus alpinus) of Frobisher Bay, Baffin Island. J. Fish. Res. Bd. Canada 10(6): 326-370.
1954. Polychaetous annelids of Ungava Bay, Hudson Strait, Frobisher Bay and Cumberland Sound. J. Fish. Res. Bd. Canada 11(5): 507-528.
1959. The annual oceanographic cycle at Igloolik in the Canadian arctic. I. The zooplankton and physical and chemical observations. J. Fish. Res. Bd. Canada 16(4): 453-501.
1961. The copepods Calanus glacialis Jaschnov and Calanus finmarchicus (Gunnerus) in Canadian arctic-subarctic waters. J. Fish. Res. Bd. Canada 18(5): 663-678.
1962. Zooplankton of Foxe Basin in the Canadian arctic. J. Fish. Res. Bd. Canada 19(3): 377-400.
1963. Copepods of the genus Calanus as indicators of eastern Canadian waters. Roy. Soc. Can. Spec. Publ. 5: 68-94.
1965. Zooplankton from the Arctic Ocean and adjacent Canadian waters. J. Fish. Res. Bd. Canada 22(2): 543-564.
1968. Invertebrate animals, p. 351-360. In C. S. Beals and D. A. Shenstone. (ed.) Science, history and Hudson Bay. Dept. of Energy, Mines and Resources, Ottawa.
1971. Biological oceanographic observations in Frobisher Bay. I. Physical, nutrient and primary production data, 1967-1971. Tech. Rep. Fish. Res. Bd. Canada, 265: 75 pp.
- 1971a. Biological oceanographic observations in Frobisher Bay. II. Zooplankton data, 1967-1970. Fish. Res. Bd. Canada Tech. Rep. 266: 61 pp.

1974. Nutrients in the southern Beaufort Sea. In J. C. Reed and J. E. Sater (ed.) The coast and shelf of the Beaufort Sea. Arctic Institute of North America, Arlington, Va., U.S.A.: 589-607.

1974a. Baseline study of the marine environment in the area of the Mackenzie delta. In The marine ecology of the Mackenzie delta and Tuktoyaktuk Peninsula region. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Report No. 74-22, part IIIa: 101-174.

In press. Primary production in Frobisher Bay, arctic Canada.

In M. J. Dunbar (ed.) Synthesis volume on marine productivity, International Biological Program. Cambridge University Press.

and K. Grohe. 1975. Zooplankton data from the Beaufort Sea, 1951 to 1975. Environment Canada, Fisheries and Marine Service, Technical Report 591.

and J. E. Lovrity. 1975. Physical and chemical oceanographic data from the Beaufort Sea, 1960 to 1975. Environment Canada, Fisheries and Marine Service, Technical Report 590.

